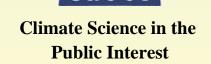


#### **Philip Mote**

Climate Impacts Group University of Washington

With contributions from Alan Hamlet, Nate van Rheenan, Richard Slaughter, Don Reading, Lara Whitely Binder, Rick Palmer

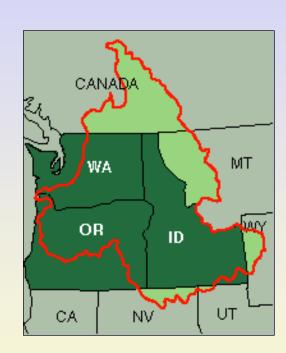
philip@atmos.washington.edu (206) 616-5346



## The Climate Impacts Group

http://www.cses.washington.edu/cig/

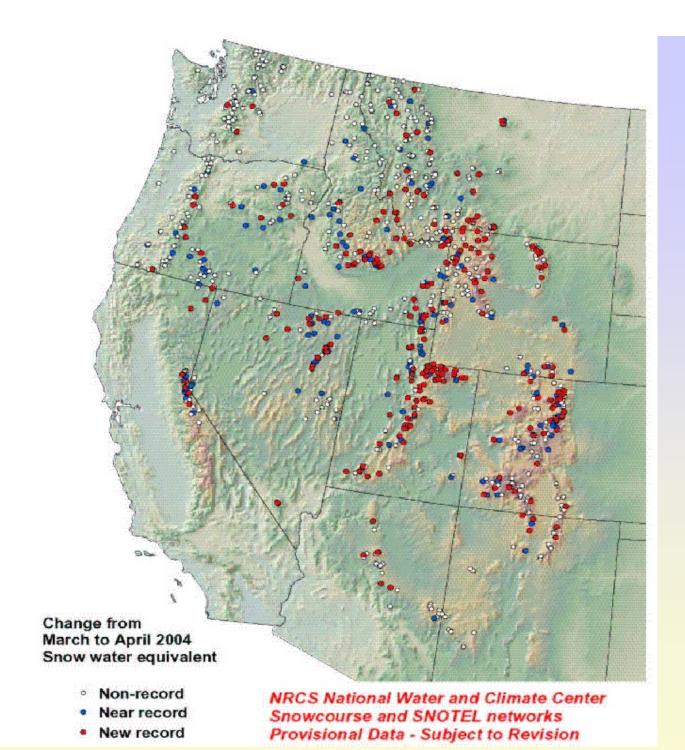
- Goal: help the region become more resilient to climate variations and climate change
- Primary research areas:
  - climate dynamics, water, salmon, forests, coasts
  - application of the research in managing these sectors
- Supported by NOAA Office of Global Programs



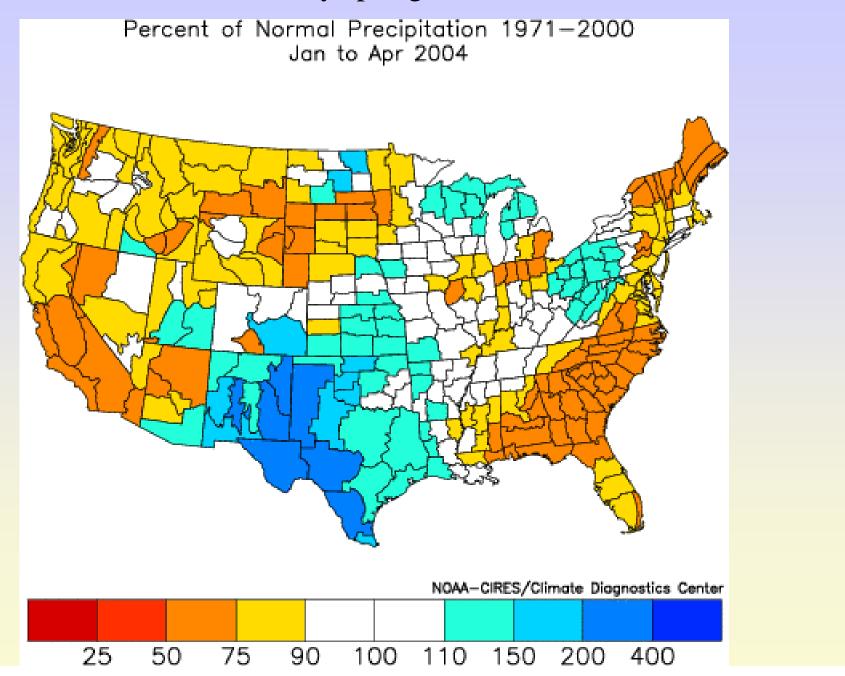
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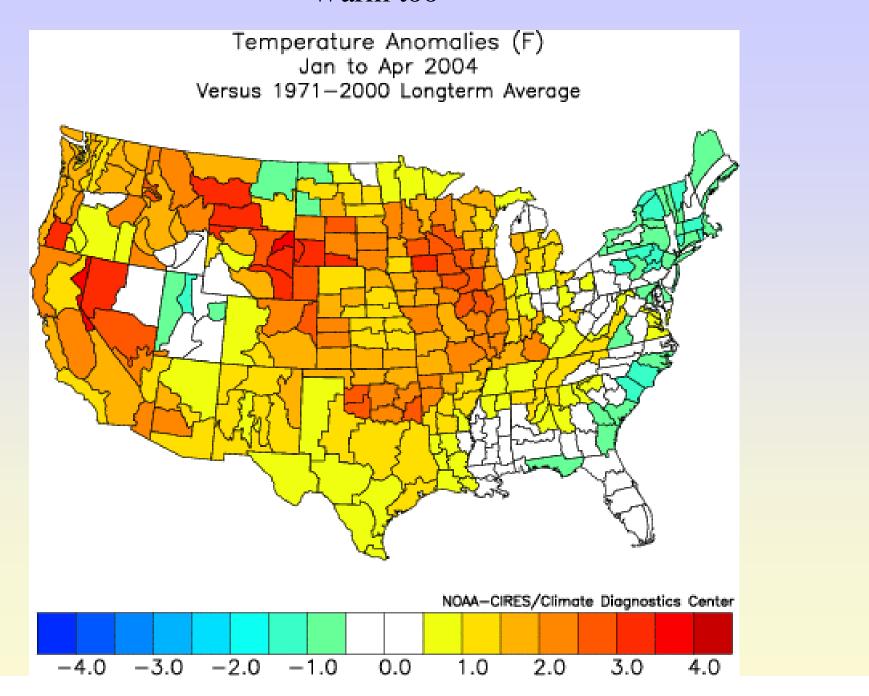
## The context: recent drought



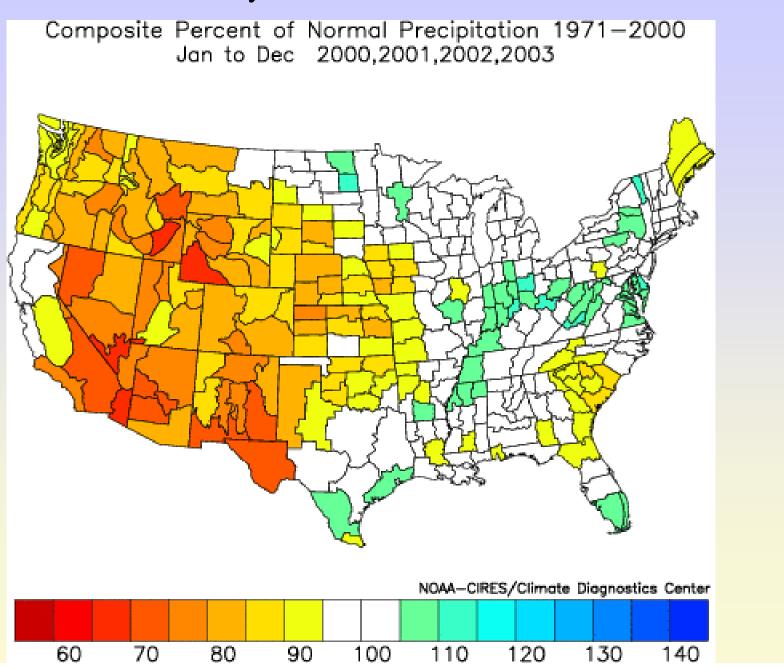
#### Dry spring 2004



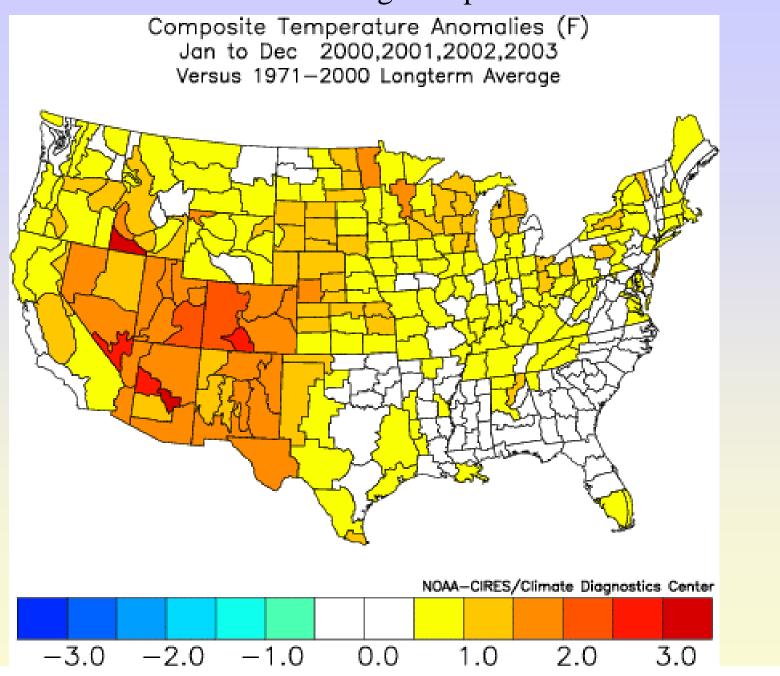
#### Warm too

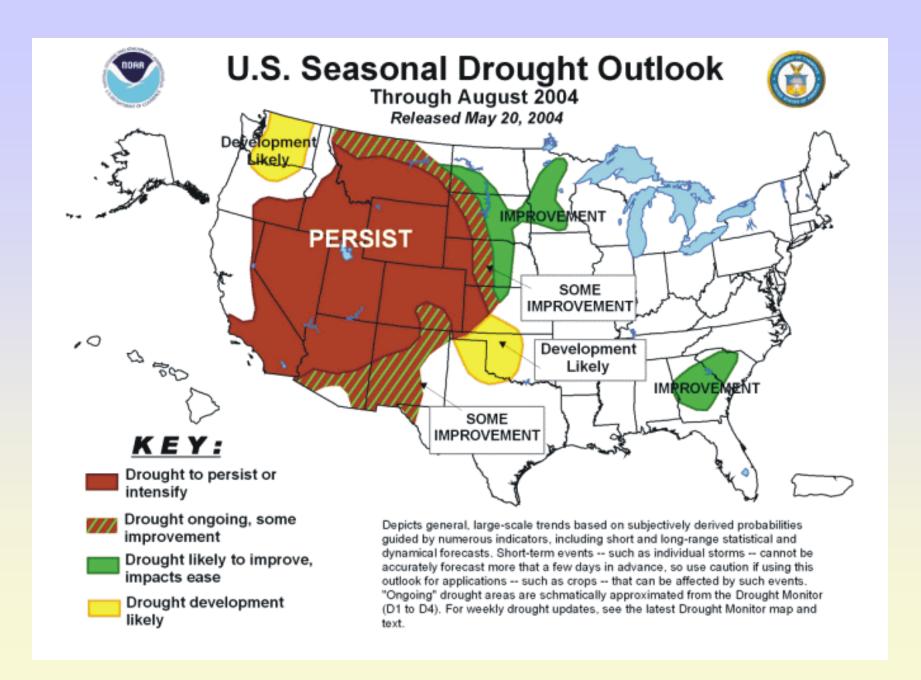


#### Several years of moisture deficit



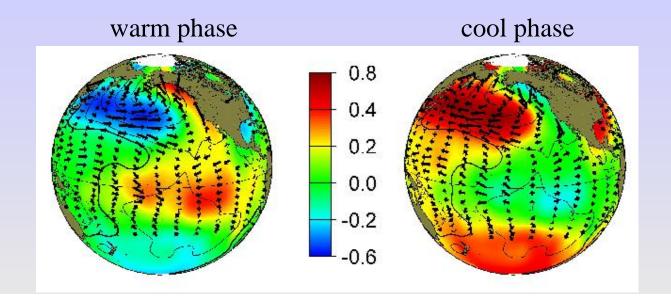
#### ...and above-average temperatures





## Idaho's climate is partly driven by the Pacific Decadal Oscillation (PDO)

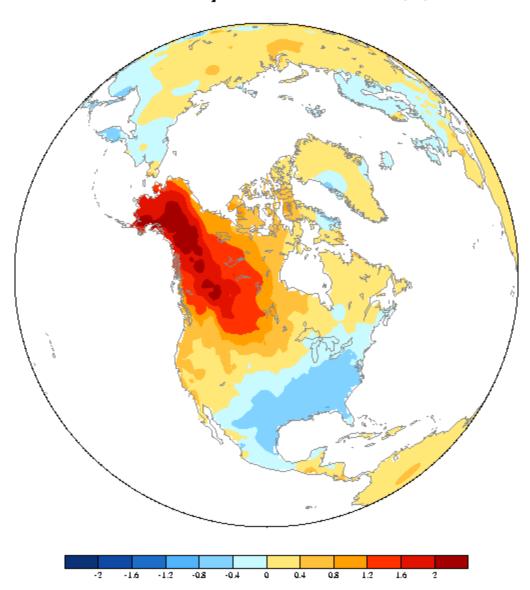




If this graph does not appear, see http://jisao.washington.edu/pdo/

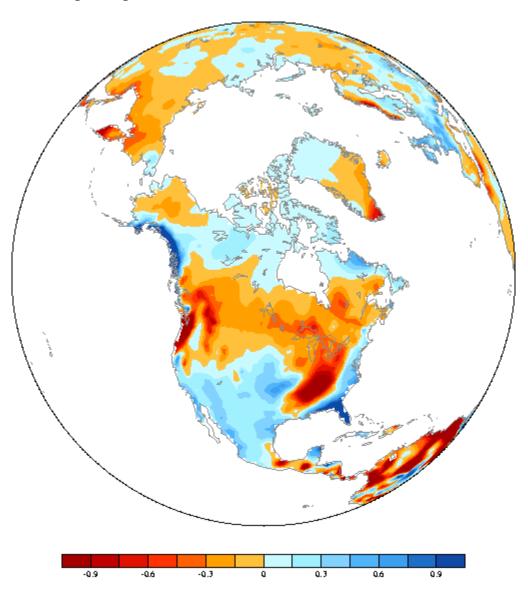
0

#### PDO surface air temperature anomalies (C) 1950-96



0

#### PDO precipitation anomalies (cm/month) 1950-96



## The context

Recent warm dry climate is not just PDO

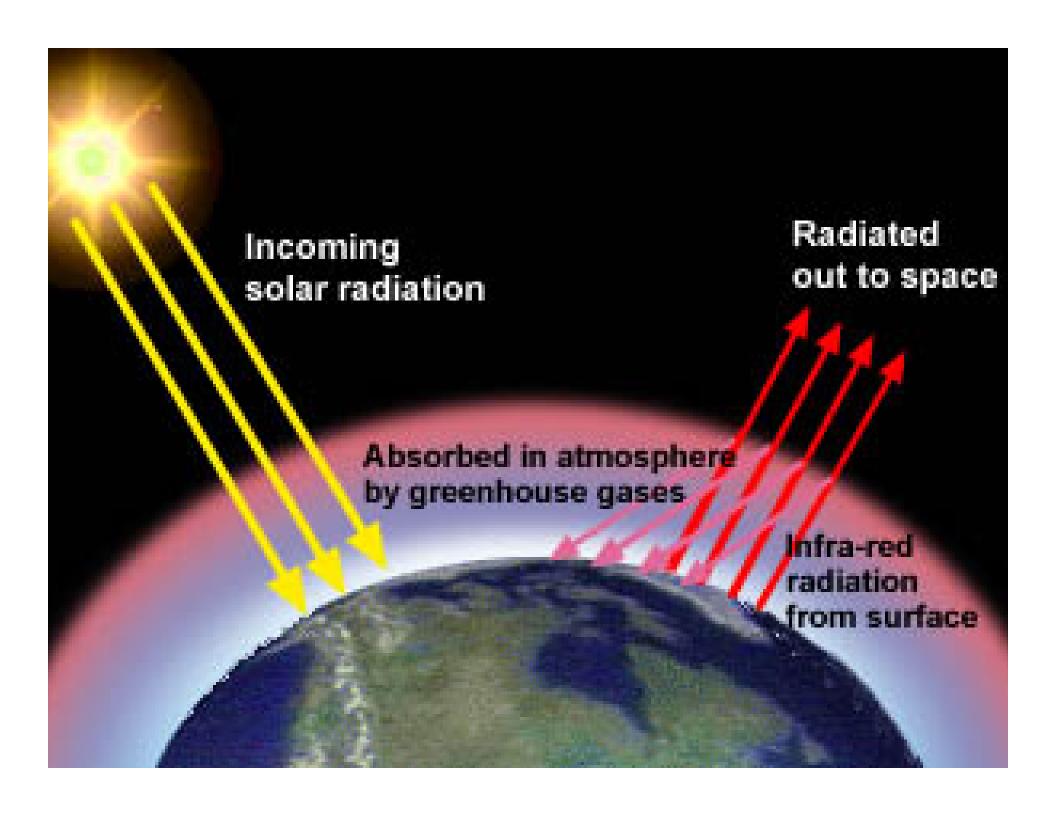
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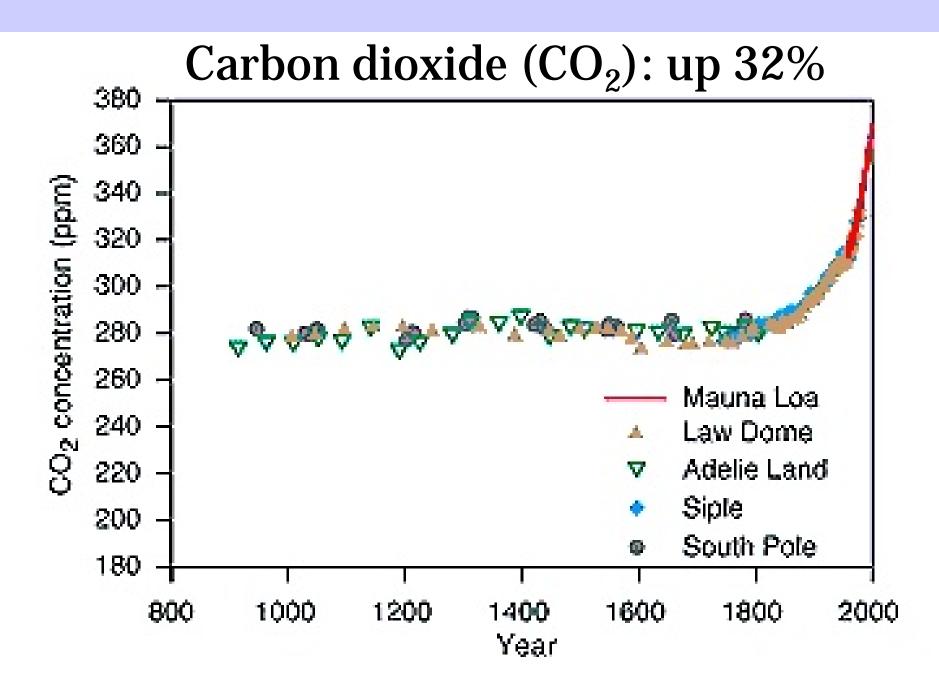
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## Science of climate change

- Thousands of peer-reviewed scientific papers
- Intergovernmental Panel on Climate Change (IPCC)
- Major reports in 1990, 1996, 2001
- Conclusions:
  - "An increasing body of observations gives a collective picture of a warming world and other changes in the climate system."
  - "There is new and stronger evidence that most of the warming observed over the last 50 years is attributable to human activities."

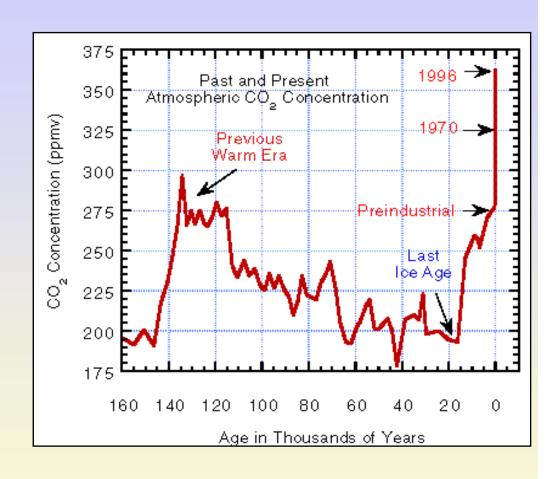






## CO<sub>2</sub> over the last 160,000 yr

- Appears to be higher than any time in past ~23 million yrs
- ~70% of CO<sub>2</sub> emissions come from fossil fuel burning

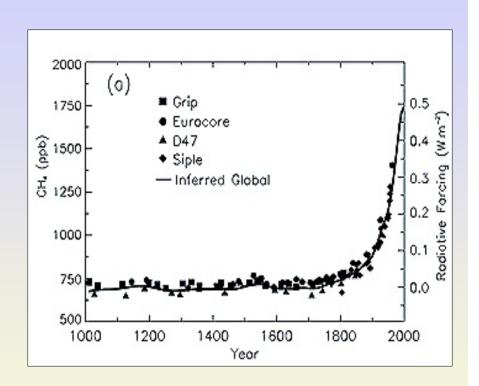


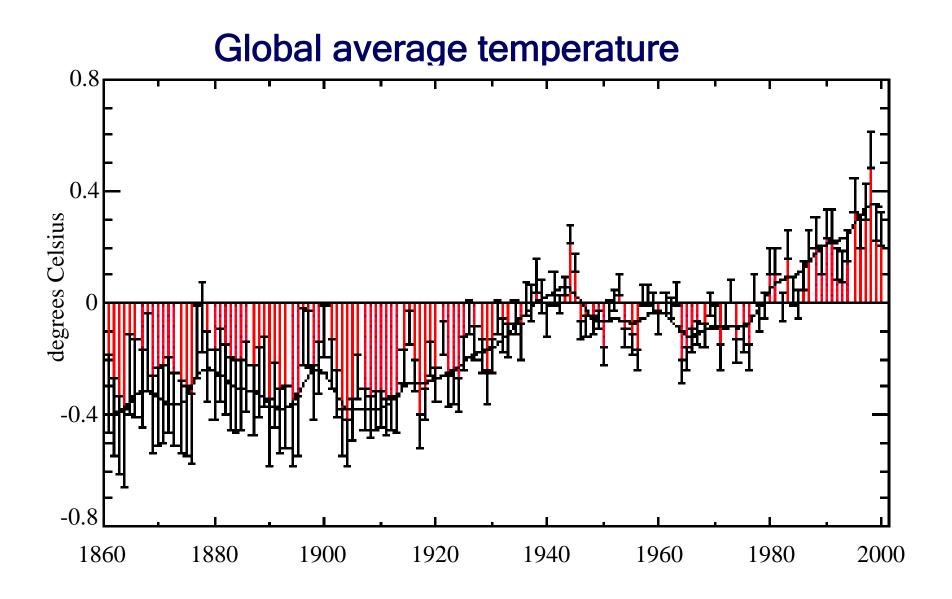
From a long term perspective, these changes are enormous



## Methane (CH4)

- Has increased ~150% since1750
- Current concentration has not been exceeded in at least 420,000 years
- Slightly more than 50% of CH<sub>4</sub> emissions originate from human activities
- More potent greenhouse gas than CO<sub>2</sub>, per molecule, but less abundant





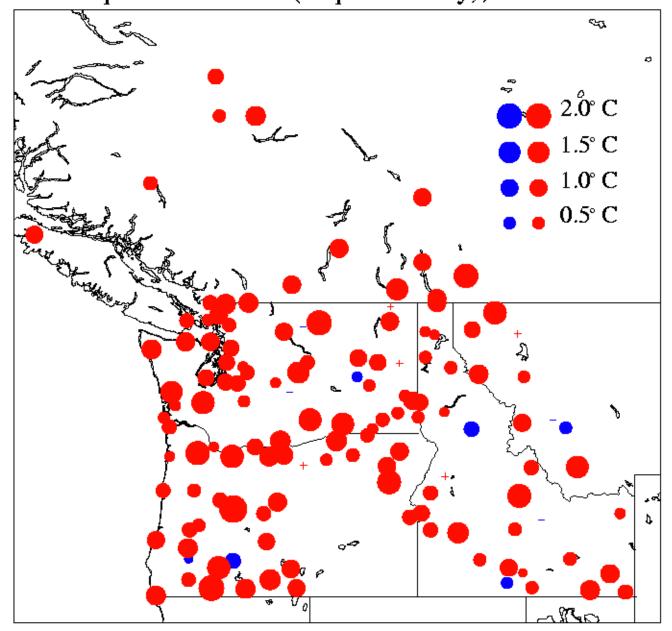
# Could these measurements be wrong?

Urbanization?

 Perhaps 10% of warming; lots of natural evidence

- Stations too sparse?
- Warming patterns very big
- Satellite measurements show no warming?
- Surface definitely warming;
   troposphere warming 1960-2001 but not 1979-2001

Temperature trends (°C per century), since 1920





The South Cascade glacier retreated dramatically in the 20th century

Courtesy of the USGS glacier group

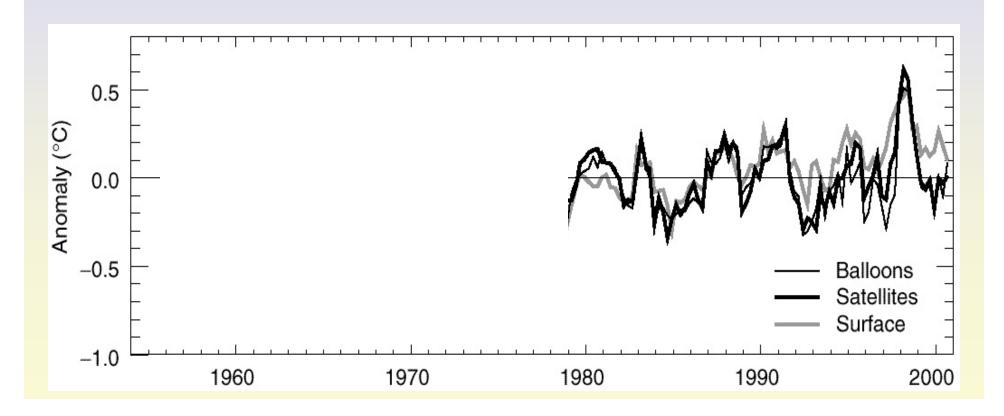
1928



## those satellite observations

Models: troposphere (0-5 miles) should warm *faster* than surface

But satellites show little warming since 1979: does this mean that surface measurements are unreliable?

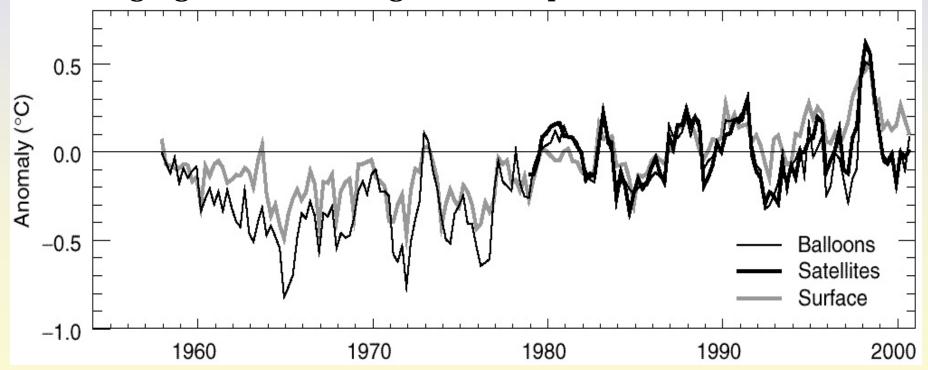




The complete picture: troposphere has warmed

National Academy: satellite measurements "in no way invalidates the conclusion that surface temperature has been rising

Emerging understanding: ozone depletion a factor?

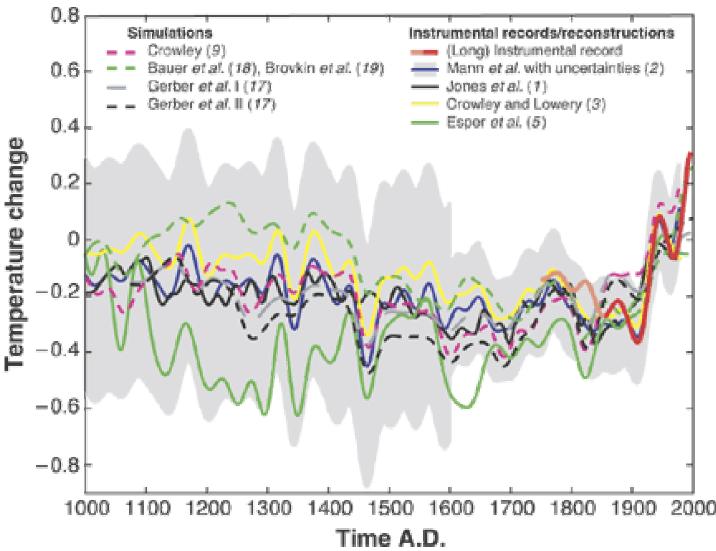


## Some evidence that it's not natural

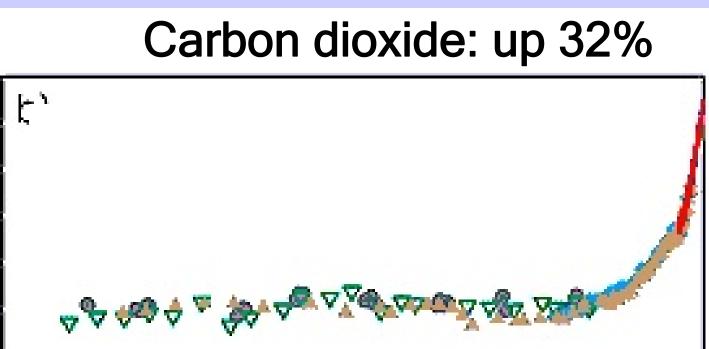
- Rate of change appears to be unusual
- Pattern of change matches that expected from increasing greenhouse gases
- Solar, volcanic forcing would have led to cooling in the past ~30 years

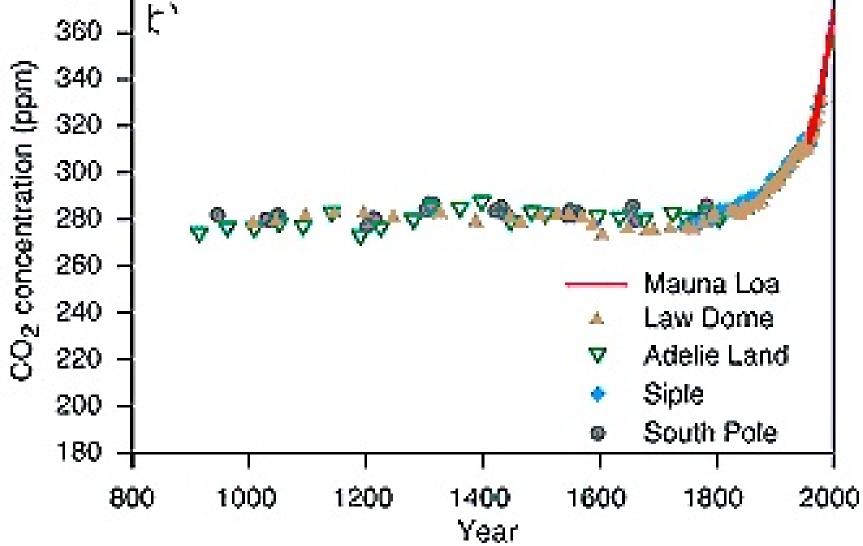
#### Long-term context

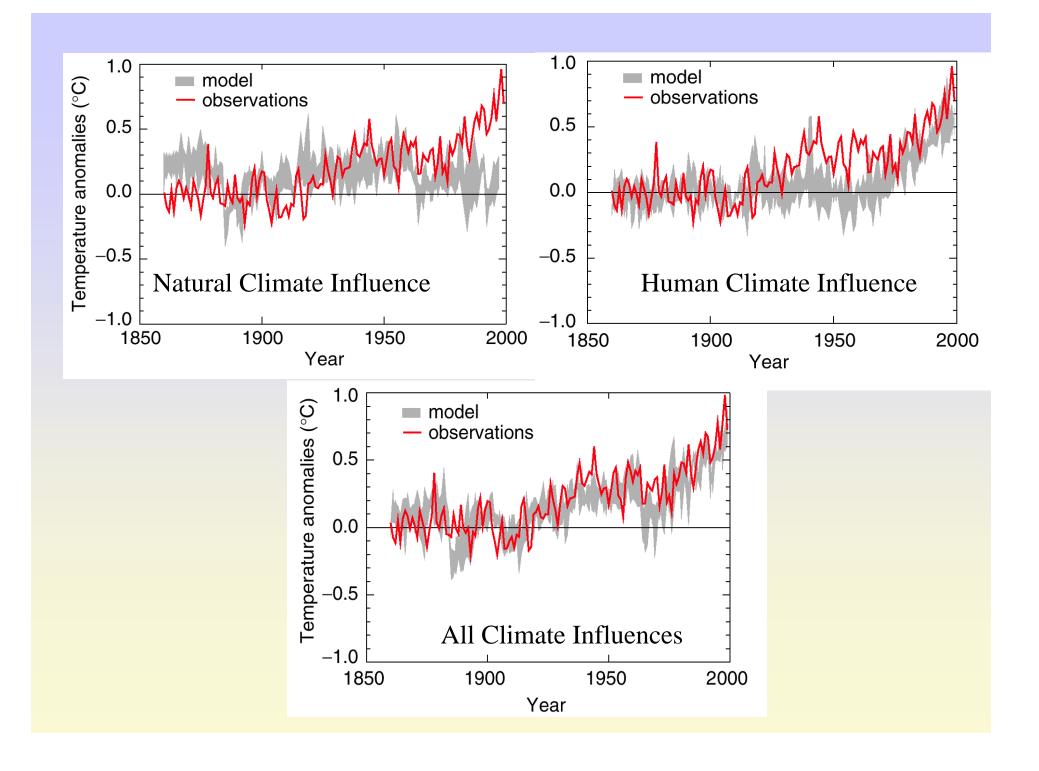




source: Mann et al., EOS









## Solar output varies - but not much

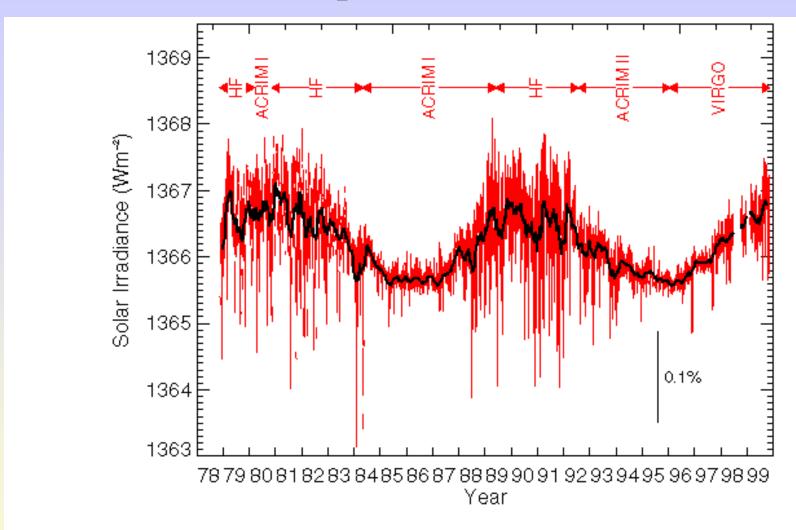


Figure courtesy of NOAA National Geophysical Data Center

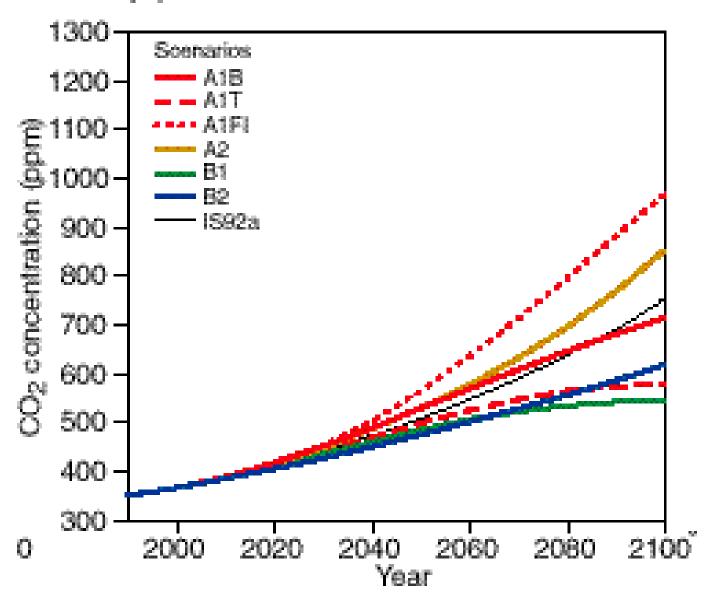
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THE DAY AFTER TOMORROW IN THEATRES WORLDWIDE 28 MAY 2004 HITTER HITTER 7 - FT WHERE WILL YOU BE?

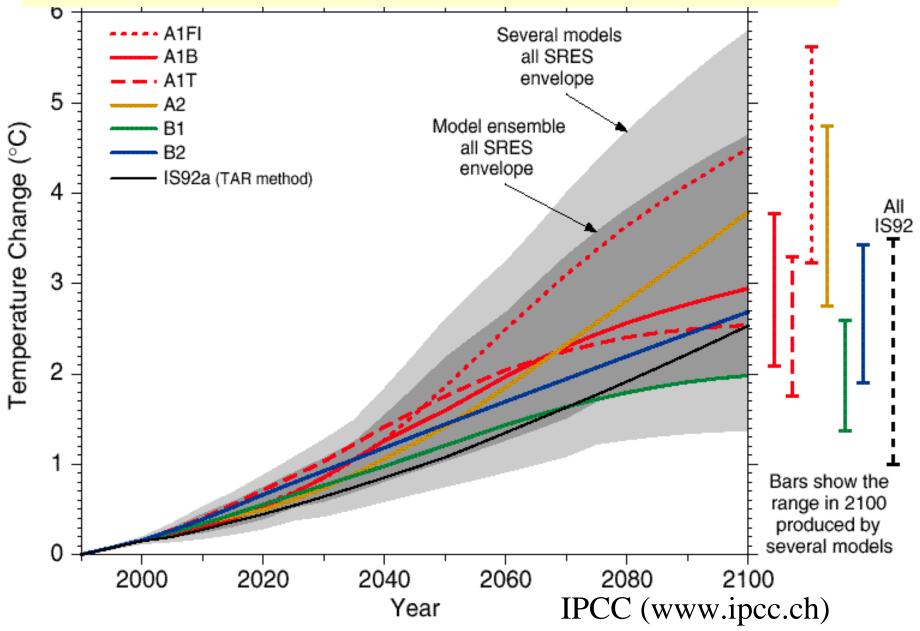
#### (b) CO<sub>2</sub> concentrations





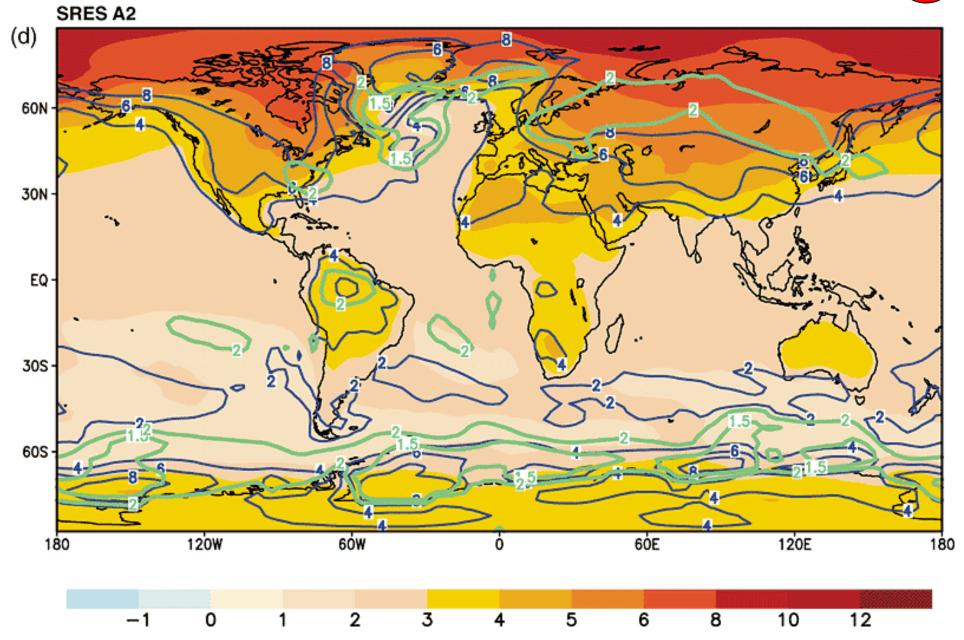
### 21st century temperature change





#### Temperature change, 2071-2100 minus 1961-1990





#### Projected PNW Climate Change



Projected changes in average annual PNW temperature and precipitation for the decades of the 2020s and 2040s.

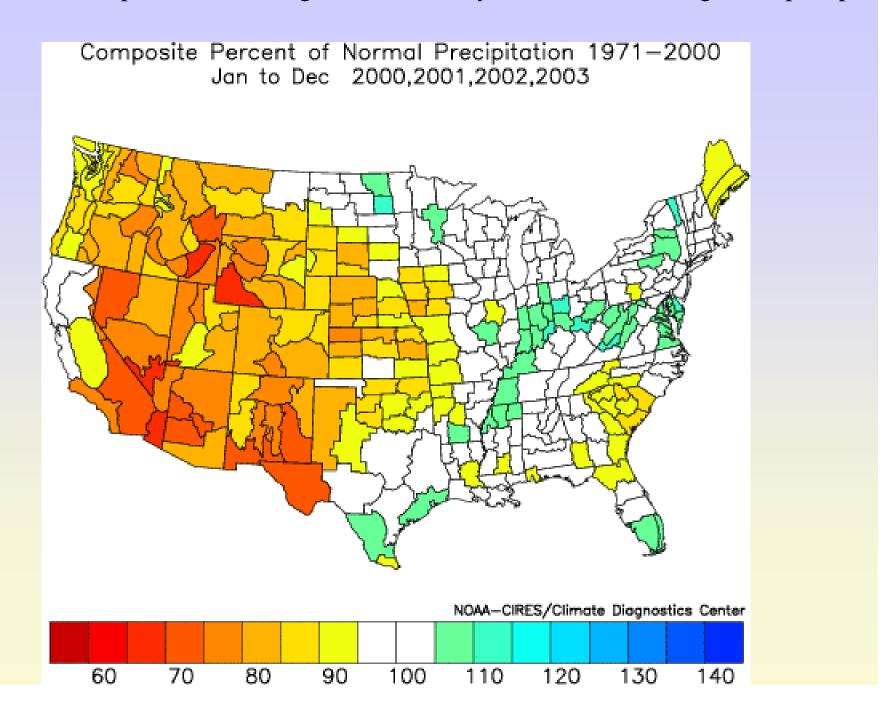
high confidence lower confidence

2020s	Temperature	Precipitation
Low	+ 0.8°F	+ 2 %
Mean	+ 2.5°F	+ 7%
High	+ 3.4°F	+ 14 %

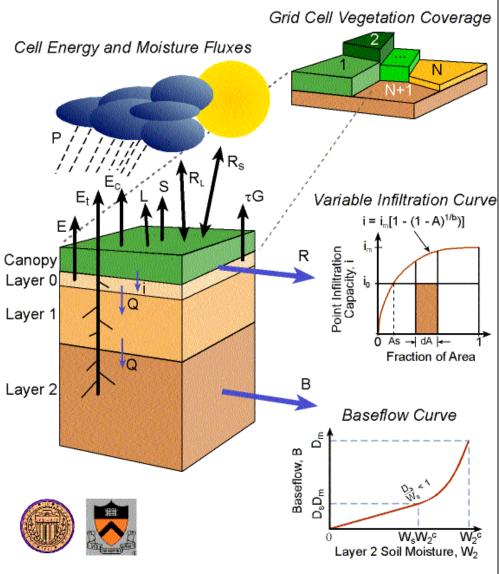
2040s	Temperature	Precipitation
Low	+ 2.7°F	- 3 %
Mean	+4.0°F	+ 7%
High	+ 4.9°F	+ 14 %

Based on an increase in equivalent  $CO_2$  of 1% per year. Benchmarked to the decade of the 1990s.

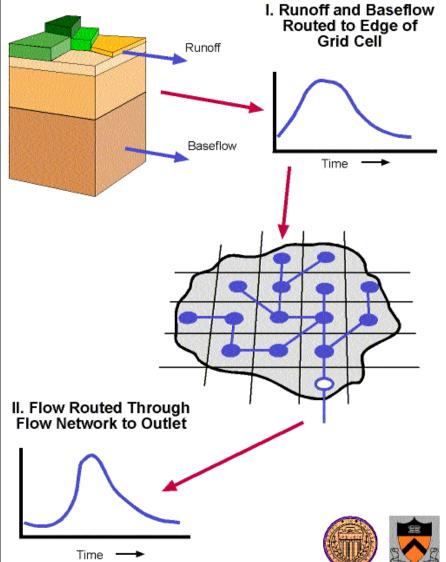
Not what we expect in a warming world - but maybe models are wrong about precip?



#### Variable Infiltration Capacity - n Layer (VIC-nL) Macroscale Hydrologic Model

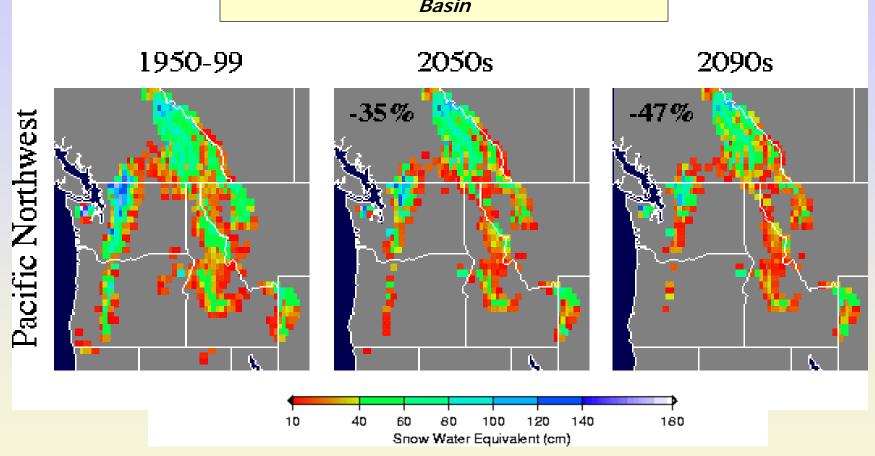


#### River Network Routing Scheme for VIC-N

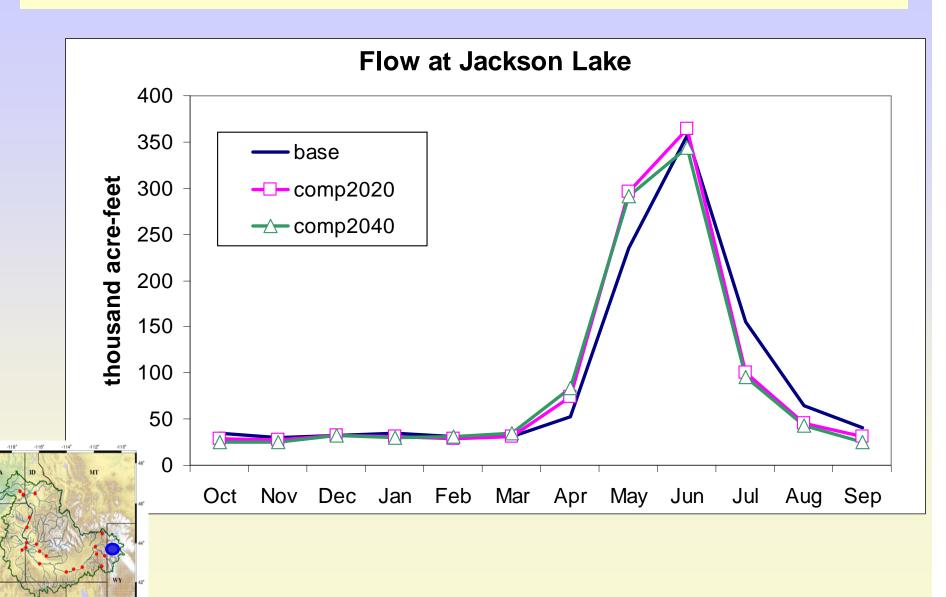


#### Main Impact: Less Snow

April 1 Snow Extent for the Columbia River Basin

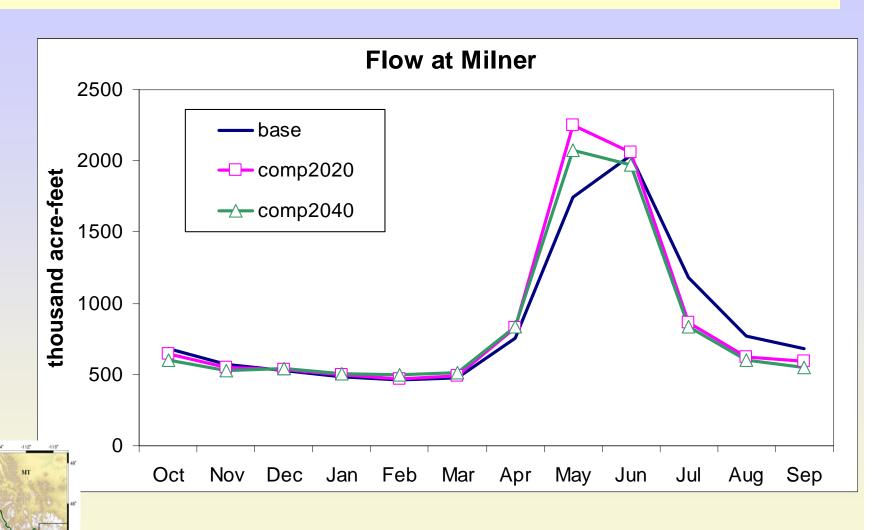


## Snake System Flows – Jackson Lk

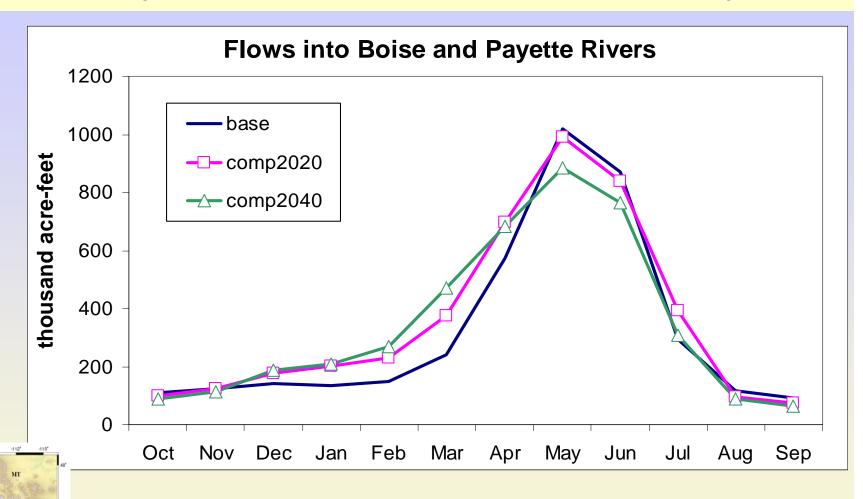


#### **Snake System Flows – Milner**

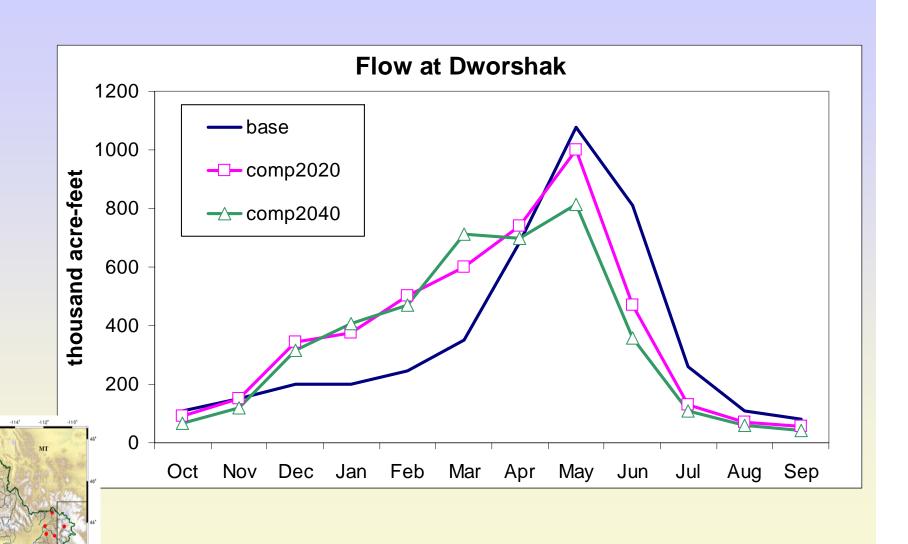




## Snake System Flows – Boise/Payet

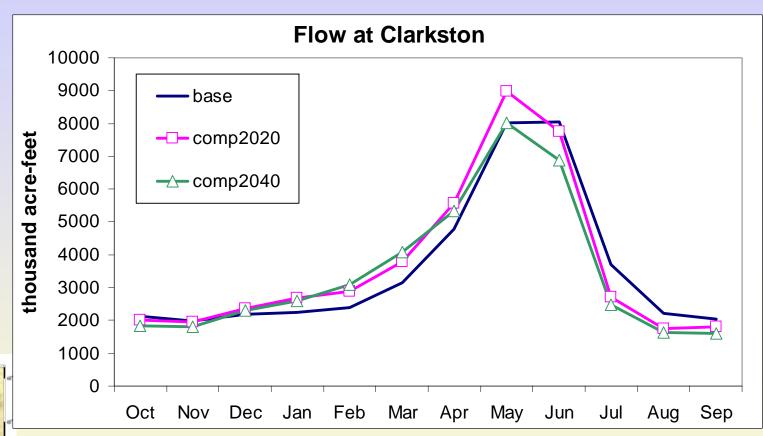


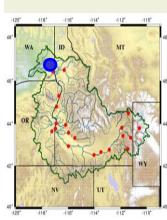
## Snake System Flows – Dworshak R



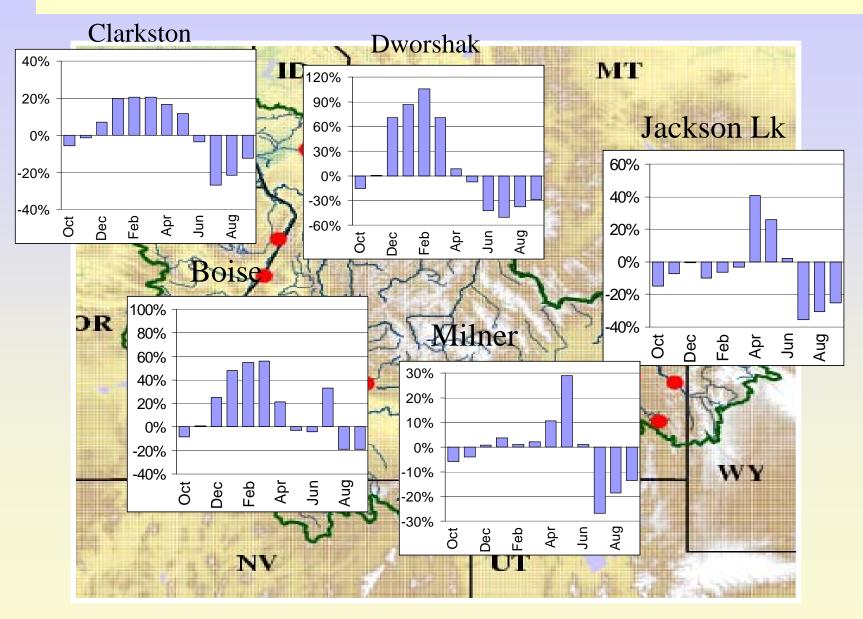
#### 0

#### **Snake System Flows – Clarkston**



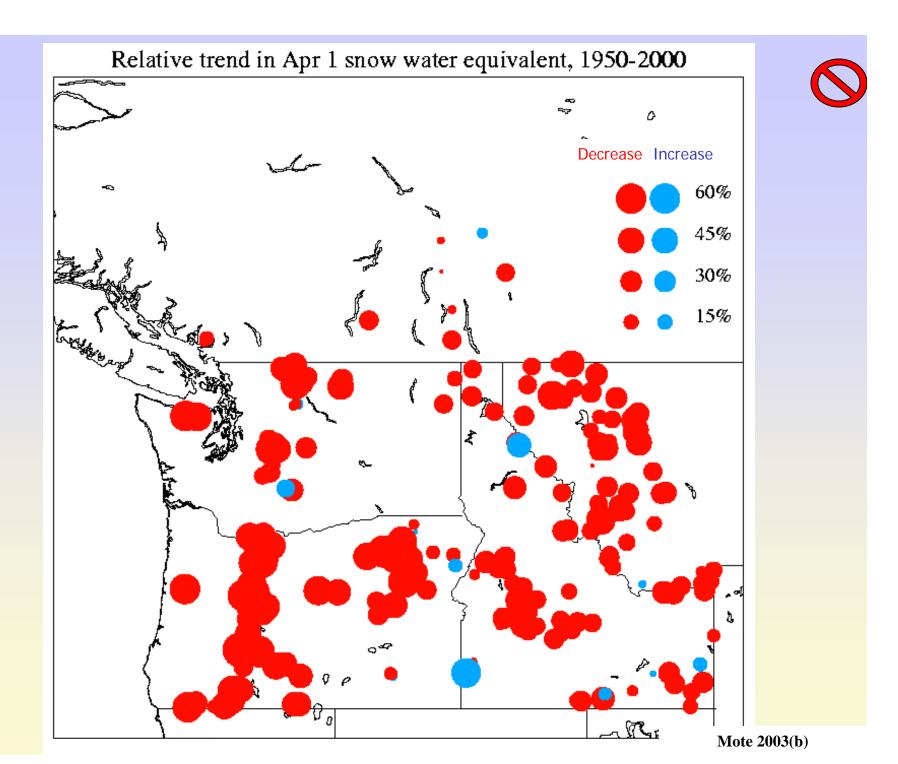


## Overall Streamflow changes - 2020s



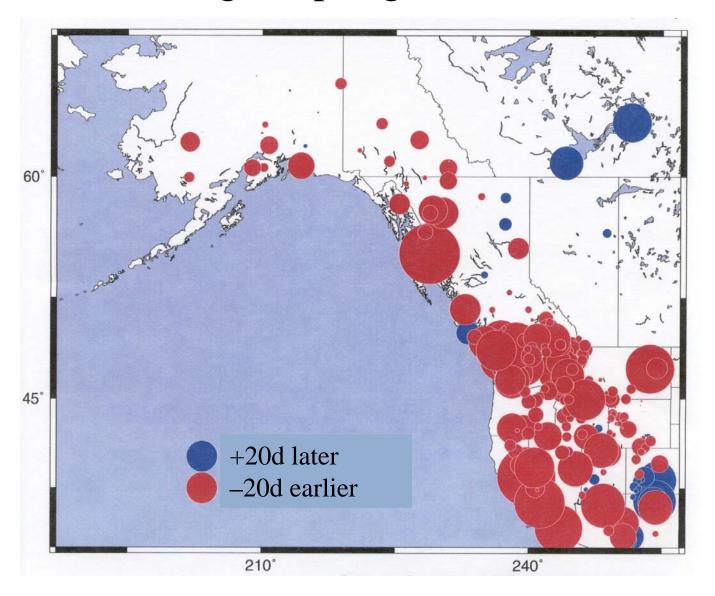
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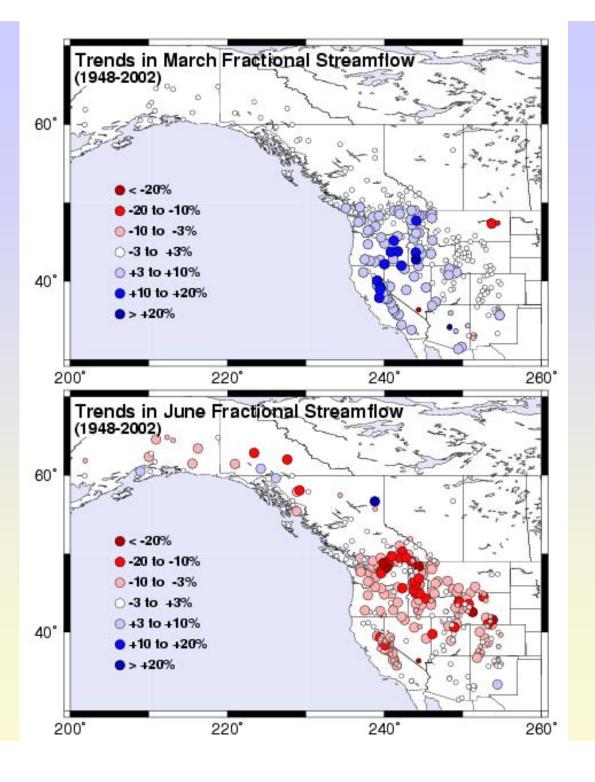


# Trends in timing of spring snowmelt (1948-2000)





Courtesy of Mike Dettinger, Iris Stewart, Dan Cayan



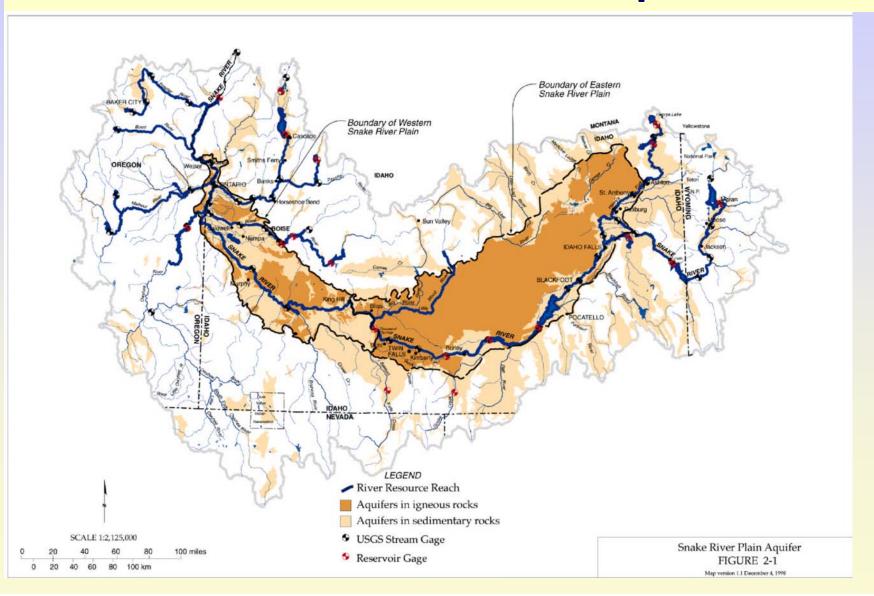
As the West warms, winter flows rise and summer flows drop

Figure by Iris Stewart, Scripps Inst. of Oceanog. (UC San Diego)

#### Three main points

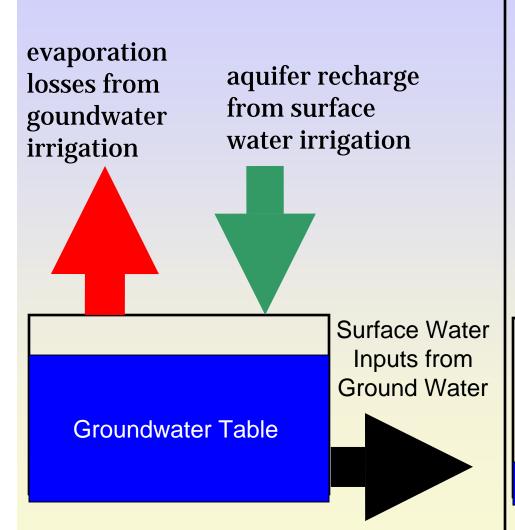
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### **Snake River Plain Aquifer**



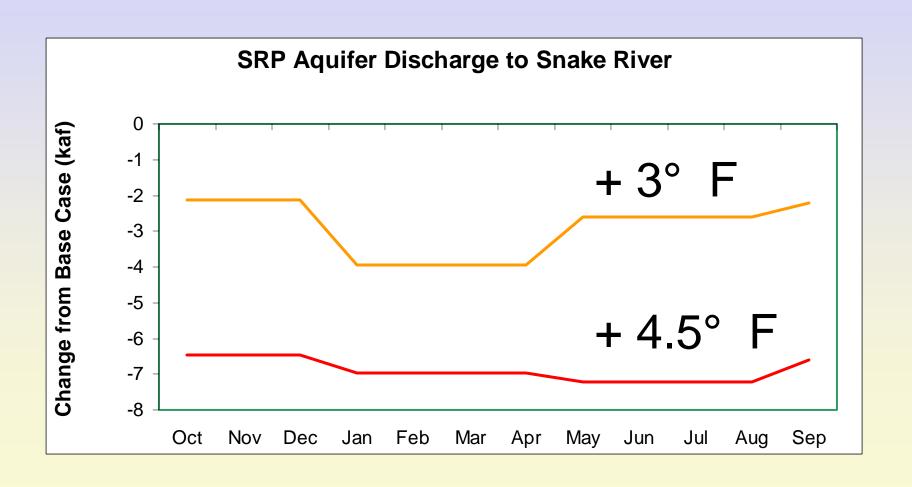
#### **Current Climate**

#### Warmer Climate



evaporation aquifer recharge losses from from surface goundwater water irrigation irrigation Surface Water Inputs from **Ground Water Groundwater Table** 

### Estimated Steady State Reductions in Snake River Plain Aquifer Discharge for Two Global Warming Scenarios



#### **Implications**

- Warming increases ET and reduces recharge: both effects reduce SRP Aquifer discharge to the Snake River
- A warmer climate will require greater effort to maintain current levels of aquifer discharge
- Beyond SRP aquifer, downstream water users will additionally be affected by loss of snowpack.

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#### Extra slides

#### Enhanced greenhouse effect

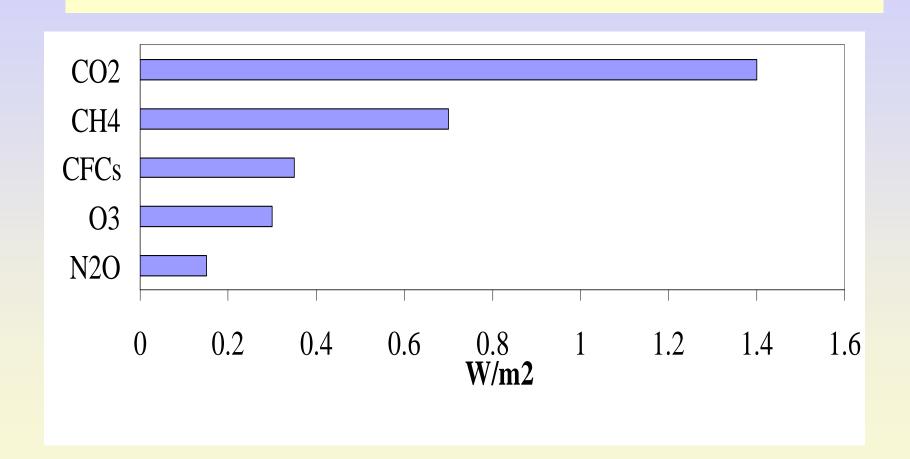
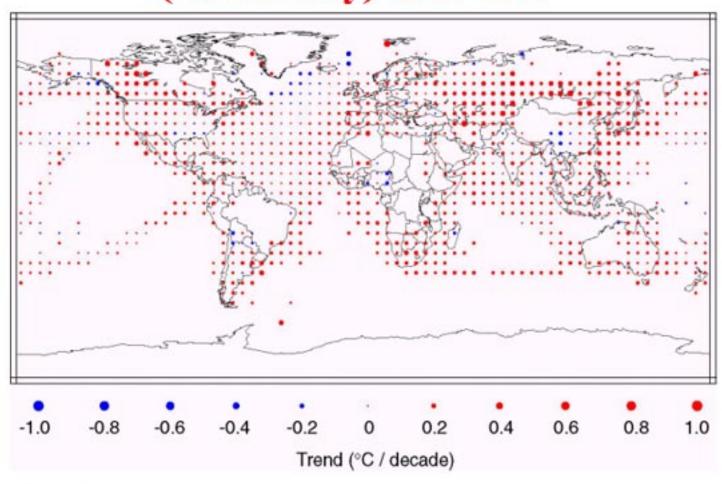
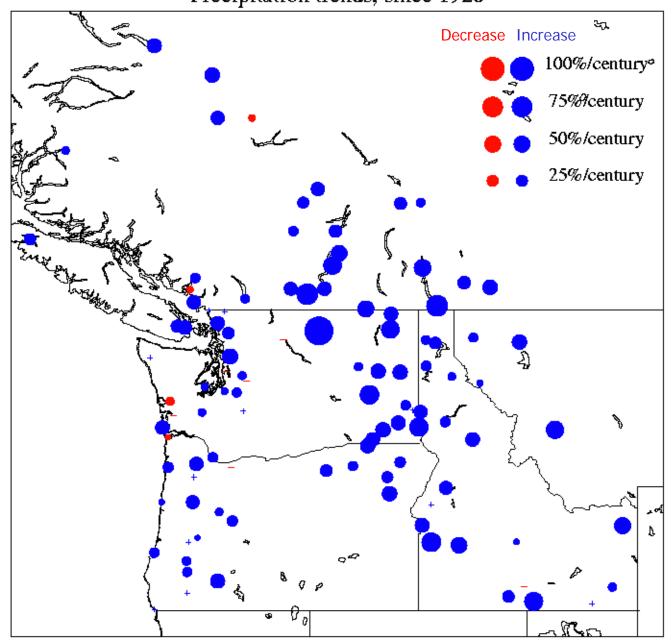


Figure 2: Annual Temperature Trends, (°C / century) 1901-1999

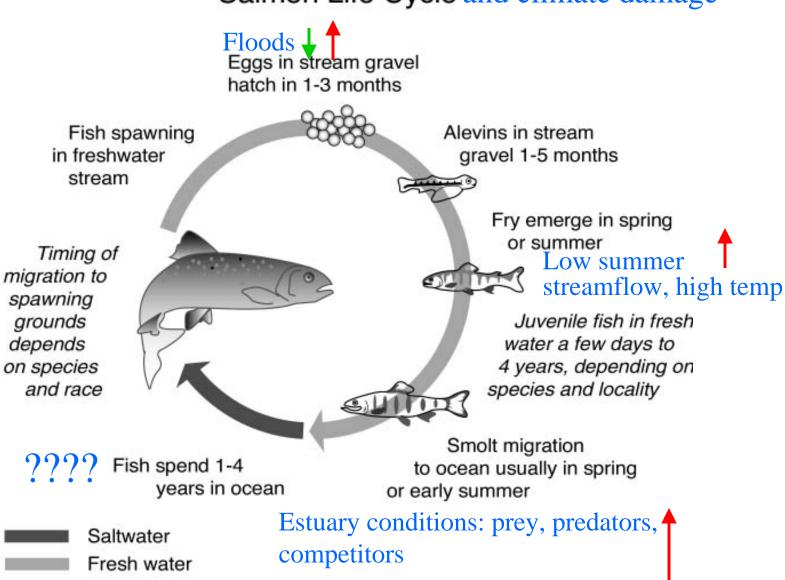


Source: P. Jones, et. al. 2000.

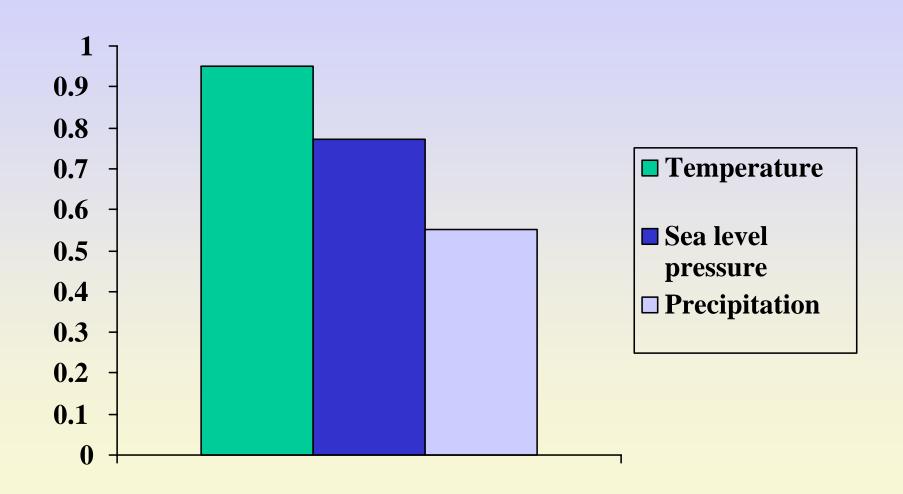
Precipitation trends, since 1920



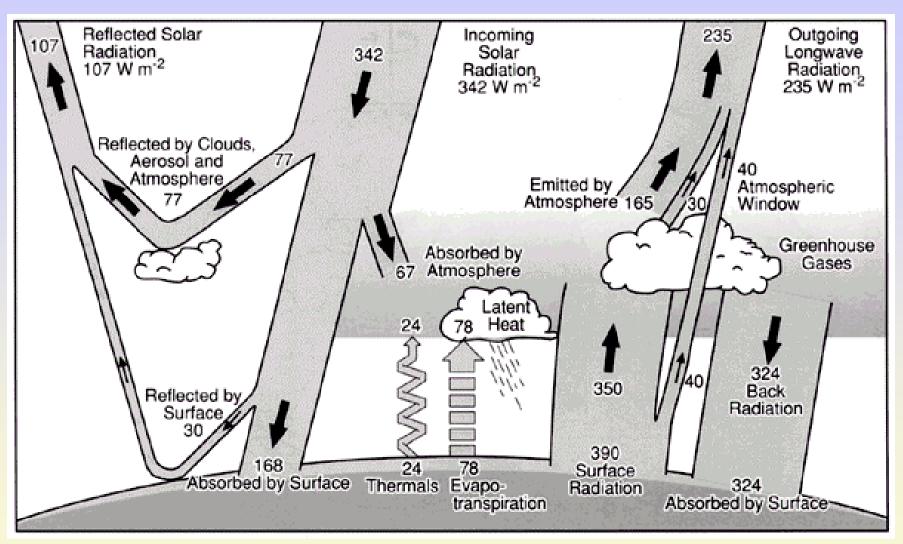
#### Salmon Life Cycle and climate damage



# Correlations of modeled and observed climate variables



#### Earth's radiation budget



From Kiehl and Trenberth, 1996

#### **Implications**

- Upstream of Milner, water supplies likely to be changed less by warming (low sensitivity, high storage)
- Downstream summer water supplies are already being eroded by loss of snowpack, especially in sensitive areas such as N. Fork Clearwater (Dworshak inflows).
- Water temperature problems in the lower basin may be exacerbated.